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(71) Applicant: Alcatel
Plano, Texas 75023 (US)

(72) Inventors:
- Xiong, Yijun
Plano, Collin County, Texas 75025 (US)
- Agrawal, Anshul
Plano, Collin County, Texas 75075 (US)
- Vandenhoute, Marc L.J.
Dallas, Denton County, Texas 75287 (US)
- Cankaya, Hakki C.
Dallas, Dallas County, Texas 75206 (US)

(74) Representative:
Dreiss, Fuhlendorf, Steimle & Becker
Patentanwälte,
Postfach 10 37 62
70032 Stuttgart (DE)

(54) **Data channel reservation in optical burst-switched networks**

(57) The present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel (or a multiple of data channels) along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at all nodes along the optical path, including the reservation termination node. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

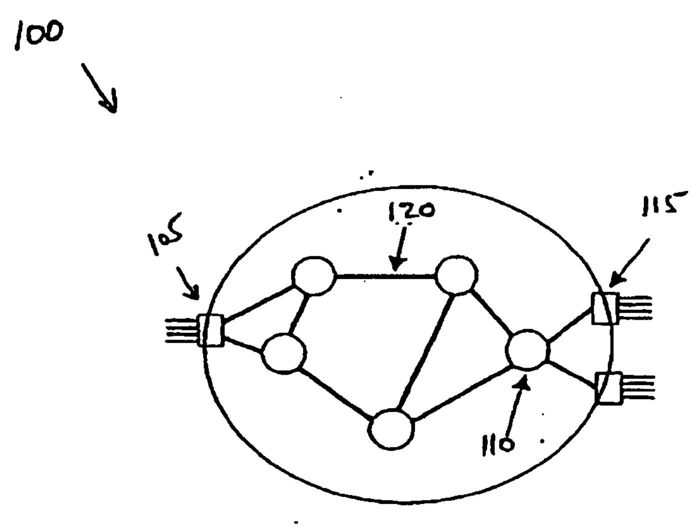

Figure 1: An optical burst-switched network.

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to optical network systems, and more particularly to a system and method for providing data channel reservation in an optical burst-switched network.

BACKGROUND OF THE INVENTION

[0002] Data traffic over networks, particularly the internet, has increased dramatically over the past several years, and this trend will continue with the introduction of new services which require more bandwidth. The enlarged volume of internet traffic requires a network with high capacity routers capable of routing data packets with variable lengths. One option is the use of optical networks. However, current optical networks use only a small fraction of the bandwidth available on a single optical fiber.

[0003] The emergence of dense-wavelength division multiplexing (DWDM) technology has helped to overcome the bandwidth problem encountered by current optical networks. A single DWDM optical fiber has the capability of carrying as much as ten (10) terabits of data per second. Different approaches advocating the use of optical technology in place of electronics in switching systems has been proposed, however the limitations of optical component technology has largely limited optical switching to facility management applications. One approach called optical burst-switched networking attempts to make the best use of optical and electronic switching technologies. The electronics provides dynamic control of system resources, assigning individual user data bursts to channels of a DWDM fiber. Optical technology is used to switch the user data channels entirely in the optical domain.

[0004] One problem with switching user data channels entirely in the optical domain is that it is difficult to setup a data channel path across an optical burst-switched network without wasting network resources such as transmission and switching capacity. Each data channel within an optical path can range from ten (10) Gbps to forty (40) Gbps and the roundtrip delay of an optical path is very long when using conventional signaling approaches. Thus, setting up an optical path with bandwidth of one or more data channels in an optical burst-switched network takes a long time and wastes a huge amount of bandwidth. If the connection time is not sufficiently long, the bandwidth wasted may not be well justified.

[0005] Another problem with optical burst-switched networks relates to data channel scheduling. Schedulers within switch control units of core routers in the optical burst-switched network are responsible for scheduling burst payloads and their corresponding burst header packets on data channel groups (DCG) and control channel groups (CCG), respectively. A burst header packet has to be processed in the switch control unit as quickly as possible, thus the scheduling algorithm must be simple and fast.

[0006] One prior art scheduling algorithm is the Latest Available Unscheduled Channel (LAUC) algorithm , also known as the Horizon algorithm. In the LAUC algorithm, only one value, the future available/unscheduled time, is remembered for each data channel. However, the LAUC algorithm results in high burst loss ratio and thus low channel utilization due to the gaps/voids between bursts. Other more sophisticated scheduling algorithms usually lead to less burst loss ratio, but their implementation are very difficult since the scheduler has to work at a very high speed (e.g., about 100 nanoseconds per burst). Thus, a simple and fast scheduling algorithm is needed to reduce the burden of schedulers in optical burst-switched networks and to improve the performance of data channel scheduling.

SUMMARY OF THE INVENTION

[0007] The present invention provides an optical burst-switched network that substantially eliminates or reduces disadvantages and problems associated with previously developed optical burst-switched networks used for switching data channels.

[0008] More specifically, the present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at the reservation termination node. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

[0009] The present invention provides an important technical advantage by providing a mechanism to use "cross connect" in the optical burst-switched network whenever possible without losing the efficiency and flexibility of burst switching.

[0010] The present invention provides another technical advantage by avoiding unnecessary hop-by-hop burst scheduling.

[0011] The present invention provides yet another technical advantage by reducing the load on schedulers of switch control units in optical core routers.

[0012] The present invention provides yet another technical advantage by reducing the gaps/voids between bursts transmitted on the reserved data channels, which in turn increases the data channel utilization.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIGURE 1 shows an optical burst-switched network according to the present invention;
FIGURE 2 shows a more detailed example of an optical burst-switched network according to the present invention;
FIGURE 3 shows a functional block diagram of an electronic edge router according to the present invention;
FIGURE 4 shows one example of the forwarding information base at an electronic edge router according to the present invention;
FIGURE 5 shows a functional block diagram of an optical core router according to the present invention;
FIGURE 6 shows one example of the label information base at an optical core router according to the present invention;
FIGURE 7 shows an example depicting the data channel path set up according to the present invention;
FIGURE 8 shows an example of the channel information base at optical core router C4;
FIGURE 9 shows an example of the channel information base at optical core router C1; and
FIGURE 10 shows an example depicting the threshold of a new queue for a reserved data channel.

DETAILED DESCRIPTION OF THE INVENTION

[0014] Preferred embodiments of the present invention are illustrated in the FIGUREs, like numerals being used to refer to like and corresponding parts of the various drawings.

[0015] FIGURE 1 shows one example of an optical burst-switched network 100. The optical burst switched network includes multiple electronic ingress edge routers 105, multiple optical core routers 110, multiple electronic egress edge routers 115, and multiple dense-wavelength division multiplexing (DWDM) optical links 120. The DWDM optical links 120 connect the electronic ingress edge routers 105, the optical core routers 110, and the electronic egress edge routers 115 together. The electronic ingress edge routers 105 and the electronic egress edge routers 115 perform burst assembly/disassembly functions and serve as legacy interfaces between the optical burst-switched network 100 and conventional electronic routers. Note that, although electronic ingress edge router and electronic egress edge router are logically distinguished in FIGURE 1, both functions are often physically combined in a single physical edge router device.

[0016] A burst, the basic data block to be transferred through the optical burst-switched network, is a collection of data packets which have the same destination (network egress address) or destinations and other attributes such as quality of service (QoS) requirements. A burst consists of a burst header packet (BHP) and a burst payload. The format of the burst header packet may consists of an Internet protocol (IP) header (e.g., IPv4, IPv6) or a multi-protocol label switching (MPLS) shim header if MPLS is used or both, together with the optical burst switching specific information which will be used by switch control units to route bursts and by electronic egress edge routers 115 to receive bursts.

[0017] FIGURE 2 shows a more detailed example of the optical burst-switched network 100. Each DWDM optical link 120 can have many data channels 205. Each data channel 205 carries a single wavelength λ. Without loss of generality, in FIGURE 2, assume here that all data channels 205 have the same transmission capacity which equals R bits per second (bps). Packets are assembled into bursts at electronic ingress edge routers 105 according to a burst assembly mechanism. The bursts are then forwarded at layer 3 or switched at layer 2 (if a MPLS type label switching mechanism is used) through the optical burst-switched network 100 to their electronic egress edge routers 115. A burst flow can be defined as a set of bursts which have the same electronic ingress edge router 105, follow the same path, and are destined to the same reservation termination node (RTN). The RTN can either be an electronic egress edge router 115 or an optical core router 110. A more strict definition of a burst flow requires that the bursts have the same or similar attributes like quality of service (QOS).

[0018] FIGURE 3 shows a functional block diagram of an electronic edge router 300 according to the present invention. The electronic edge router 300 can consist of both an electronic ingress edge router 105 and an electronic egress edge router 115. The electronic edge router 300 includes a routing processor 305, a fiber and channel database 310, a signaling processor 315, a data channel path (DCP) management module 320, a burst flow monitoring module 325, a scheduler 330, a routing information base (RIB) 335, a forwarding information base (FIB) 340, and input and output ports 355. The scheduler 330 contains a channel information base (CIB) 350.

[0019] The routing processor 305 transmits to and receives network information from neighboring communication devices through the input and output ports 355. The neighboring communication devices can be another electronic edge router 300, optical core router 110, or other communication devices. The routing processor 305 runs the routing protocols (some are optical burst switching specific), exchanges information with neighboring communication devices, and updates the RIB

335 and FIB 340. The RIB 335 contains all the necessary routing information for the network. The RIB information constantly changes and is updated with current network routing information through the routing processor 305. The FIB 340 contains next hop (i.e. outbound DCG) information for arriving bursts. The next hop could either be an electronic egress edge router 115 or an optical core router 110. The FIB 340 is created and maintained by the routing processor 305 using the RIB 335.

[0020] When using a label-swapping technique like the MPLS, an additional column is added to the FIB 340 which is used to assign a label for each outgoing burst. An example of the FIB 340 is shown in FIGURE 4. Note that only relevant information to the current invention is shown in FIGURE 4, which is also the case for other figures. The fiber and channel database 310 receives and stores network information from the routing processor 305 and the signaling processor 315. This network information includes (1) the inbound and outbound fibers and the wavelengths within each fiber; (2) the inbound and outbound data channel groups, control channel groups, and channels within each group; (3) the mapping of data channel groups, control channel groups, and channels within each group to the physical fibers and wavelengths; and (4) the status of each inbound/outbound data channel 205. The data channels 205 can be in one of three possible states. The three states are the unreserved state, the reservation in progress state, and the reserved state. When a data channel 205 is in the unreserved state, the burst flow is being scheduled on the data channel 205 in the normal way. When a data channel 205 is in the reservation in progress state, the data channel 205 is reserved, but not committed. This means that the data channel 205 will still be used in the normal fashion (i.e., as an unreserved data channel). Thus, no data channel 205 bandwidth is wasted. A "0" is placed in the CIB 350 under the status field to represent the reservation in progress state. When a data channel 205 is in the reserved state, this means that the data channel 205 is committed and bursts cannot be scheduled on the reserved data channel 205 in the normal fashion.

[0021] The signaling processor 315 also transmits to and receives network information from neighboring communication devices through input and output ports 355. The burst flow monitoring module 325 monitors the burst flow to optical core routers 110 and electronic egress edge routers 115 and informs the signaling processor 315 when the average bit rate of a flow of bursts exceeds or drops below a given threshold. The threshold is defined here as a bit rate which is no less than a data channel bit rate. If the bit rate of a flow of bursts exceeds the given threshold, the data channel 205 can be reserved. If the bit rate of a flow of bursts drops below the given threshold, part of the reserved data channel 205 is not being used, thus reservation of the reserved data channel 205 will be terminated.

[0022] The DCP management module 320 transmits and receives information to and from the signaling processor 315. The purpose of the DCP management module 320 is to keep track of all the data channel 205 paths either already reserved or in the process of being reserved. The scheduler 330 also transmits and receives information to and from the signaling processor 315. The purpose of the scheduler 330 is to schedule the transmission of bursts and their associated burst header packets on data channel groups and control channel groups, respectively. There can be a scheduler 330 for a pair of data channel group and control channel group, or a set of data/control channel group pairs. Without loss of generality, FIGURE 3 shows one scheduler 330 per data/control channel group pair.

[0023] The channel information base 350 in the scheduler 330 contains a subset of the fiber and channel database 310. This subset can include all inbound data channel groups, the outbound data channel groups and control channel groups, and the mapping to (physical) fibers and wavelengths. The outbound data channels 205 are divided into two subgroups. The two subgroups include (1) unreserved and reservation in progress data channels and (2) reserved data channels. Data channels 205 which are in the reservation in progress state operate exactly the same as data channels which are in the unreserved state. The use of reservation in progress outbound data channels is the same as unreserved outbound data channels. In addition, the channel information base 350 maintains a table for the reserved inbound and outbound data channels 205.

[0024] FIGURE 5 shows a functional block diagram of an optical core router 110 according to the present invention. The optical core router 110 includes a routing processor 505, a fiber and channel database 510, a signaling processor 515, a data channel path (DCP) management module 520, a routing information base (RIB) 525, a switch control unit (SCU) 530 and input and output ports 555. The SCU includes a forwarding information base (FIB) 540, a label information base (LIB) 545, and a scheduler 535. The scheduler 530 contains a channel information base (CIB) 550.

[0025] The routing processor 505 transmits to and receives network information from neighboring communication devices through the input and output ports 555. The neighboring communication devices can be another electronic edge router 300, optical core router 110, or other communication devices. The routing processor 505 runs the routing protocols (some are optical burst switching specific), exchanges information with neighboring communication devices, and updates the RIB 525, FIB 540, and LIB 545. The RIB 525 contains all the necessary routing information for the network. The routing information base constantly changes and is updated with current network routing information through the routing processor 505. The FIB 540 contains next hop (i.e. outbound DCG) information for arriving bursts. The next hop could either be an electronic egress edge router 115 or an optical core router 110. The FIB 540 is cre-

ated and maintained by the routing processor 505 using the RIB 525. The LIB 545 is established when a label-swapping technique like the MPLS is used to switch bursts at layer 2. Shown in FIGURE 6 is an example of the LIB 545.

[0026] The fiber and channel database 510 receives and stores network information from the routing processor 505 and the signaling processor 515. This network information includes (1) the inbound and outbound fibers and the wavelengths within each fiber; (2) the inbound and outbound data channel groups, control channel groups, and channels within each group; (3) the mapping of data channel groups, control channel groups, and channels within each group to the physical fibers and wavelengths; and (4) the status of each inbound/outbound data channel 205. Again, the data channels 205 can be in one of three possible states. The three states are the unreserved state, the reservation in progress state, and the reserved state. When a data channel 205 is in the unreserved state, the burst flow is being scheduled on a data channel 205 in the normal way. When a data channel 205 is in the reservation in progress state, the data channel 205 is reserved, but not committed. This means that the data channel 205 will still be used in the normal fashion (i.e., as an unreserved data channel) Thus, no data channel 205 bandwidth is wasted. A "0" is placed in the CIB 550 under the status field to represent the reservation in progress state. When a data channel 205 is in the reserved state, this means that the data channel 205 is committed and bursts cannot be scheduled on the reserved data channel 205 in the normal fashion.

[0027] The signaling processor 515 also transmits to and receives network information from neighboring communication devices through input and output ports 555. The DCP management module 520 transmits and receives information to and from the signaling processor 515. The purpose of the DCP management module 520 is to keep track of all the data channel paths either already reserved or in the process of being reserved. The scheduler 535 also transmits and receives information to and from the signaling processor 515. The purpose of the scheduler 535 is to schedule the transmission of bursts and their associated burst header packets on data channel groups and control channel groups, respectively. The scheduler 535 at the optical core router 110 schedules the switching of bursts from the inbound data channel groups to the outbound data channel groups and the transmission of the associated burst header packets on the outbound control channel groups. There can be a scheduler 535 for a pair of data channel group and control channel group, or a set of data/control channel group pairs. Without loss of generality, FIGURE 5 shows one scheduler 535 per data/control channel group pair.

[0028] The channel information base 550 in the scheduler 535 contains a subset of the fiber and channel database 510. This subset can include all inbound data channel groups, the outbound data channel groups and control channel groups, and the mapping to (physical) fibers and wavelengths. The outbound data channels are divided into two subgroups. The two subgroups include (1) unreserved and reservation in progress data channels and (2) reserved data channels. Data channels 205 which are in the reservation in progress state operate exactly the same as data channels which are in the unreserved state. In addition, the channel information base 550 maintains a table for the reserved inbound and outbound data channels 205 (see FIGURE 9).

[0029] Referring back to FIGURE 2, a burst can only be transmitted at the bit rate of a data channel 205, although the total transmission capacity of a DWDM optical link 120 is much larger than that of a single data channel 205. If the average bit rate of a flow of bursts from an electronic ingress edge router 105 to an electronic egress edge router 115 is identified to be larger than a data channel rate, at least one data channel 205 could be reserved on the path between the electronic ingress edge router 105 to the electronic egress edge router 115, either via default route or explicit route. By doing so, gaps/voids could be largely eliminated on the reserved data channels 205 along the path right from the electronic ingress edge router 105. Furthermore, the load of the corresponding schedulers is reduced as no scheduling needs to be done for a reserved data channel 205, except updating the data channel 205 unscheduled (or future available) time. Traffic flow that cannot be accommodated by the reserved data channel 205 path can be forwarded hop-by-hop to the electronic egress edge router 115 as before. This methodology is not limited to an electronic ingress edge router 105 and electrocnic egress edge router 115 pair. It can also be extended to any pair of electronic ingress edge router 105 and optical core routers 110 in the optical burst-switched network 100.

[0030] In FIGURE 2, assume that the average bit rate X of a burst flow from electronic ingress edge router E_1 to a RTN, say optical core router C_4, is detected by the burst flow monitoring module 325 to be $R+\Delta$ bps where $\Delta \geq 0$. The burst flow monitoring module 325 will first notify the signaling processor 315. The electronic ingress edge router E_1 may then decide to reserve a data channel 205 along a path for the flow so that a large portion of the traffic ($=R/(R+\Delta)$) will be transported via the reserved data channel 205. It is expected that gaps/voids on the reserved data channel 205 can be substantially reduced or even largely eliminated if Δ is sufficiently large or the fluctuation of the burst flow is small. To reserve a data channel 205 path, the signaling processor 315 first consults with the routing processor 305 for a route from the electronic ingress edge router E_1 to the optical core router C_4. Suppose the route given by the routing processor 305 is E_1-C_1-C_2-C_3-C_4, which could be an existing route used by the flow or a new route.

[0031] To reserve a data channel 205 along the path, the signaling processor 315 at electronic ingress edge

router E_1 first finds an unreserved outbound data channel 205 connecting to the optical core router C_1, say λ_i, from the fiber and channel database 310. It then sends out a Data-Channel-Reservation-Request (DCR-Request) message 705 to optical core router C_1, indicating that outbound data channel λ_i will be reserved for the flow as shown in FIGURE 7. The status of λ_i is changed by the signaling processor 315 from unreserved to reservation in progress in the fiber and channel database 310 as well as in the CIB 350. The DCR-Request message 705 contains the path information and the outbound data channel identifier among others, e.g., (E_1, C_1, C_2, C_3, C_4, λ_i) in this case. The information carried by the DCR-Request message 705 will be stored in the DCP management module 320.

[0032] The signaling processor 515 at optical router C_1 determines that the next hop is optical core router C_2 from the received DCR-Request message 705 sent by electronic edge router E_1. It assigns an unreserved outbound data channel 205, say λ_j, to the burst flow and then sends the modified DCR-Request message 705 - (now with λ_j) to the next optical core router C_2. The status of λ_i and λ_j are changed by the signaling processor 515 from the unreserved state to the reservation in progress state in the fiber and channel database 510 and the status of λ_j is also changed in the corresponding CIB 550 of optical core router C_1. The information carried by the DCR-Request message 705 will be stored in the DCP management module 520. It is assumed here that the error-free transmission of messages between two adjacent signaling processors is guaranteed by the lower layer protocols.

[0033] The same procedure is repeated at optical core routers C_2, C_3 and C_4. Suppose outbound data channel λ_n of optical core router C_3 is chosen for the path (see FIGURE 7). At optical core router C_4, the CIB 550 simply records that inbound channel λ_n is in the status of reservation in progress (set by optical core router C_3) as shown in FIGURE 8, where status "1" means the channels are reserved, "0" means the channels are in the reservation process, and symbol "-" means this optical core router C_4 is a RTN. Optical core router C_4 will send back a DCR-acknowledgement (DCR-ACK) message 710 to optical core router C_3, which in turn goes through optical core routers C_2, C_1, and finally reaches electronic ingress edge router E_1. Upon receiving the DCR-ACK message 710, a router (core 110 or edge 105) in the path will create a new entry in the CIB of the scheduler, specifying that the inbound and outbound data channels 205 are in the reservation process. An example of CIB 550 at optical core router C_1 is shown in FIGURE 9. FIGURE 9 shows a channel information base 550 table. The CIB 550 table shows the name of the DCG_in, G_r. Furthermore, the CIB 550 shows that channel_in has a wavelength of λ_x, channel_out has a wavelength of λ_y, and the status of the data channel 205 is "1", which means the data channel 205 is reserved. The CIB 550 table in FIGURE 9 also shows another DCG_in, G_s. The CIB 550 also shows that channel_in has a wavelength of λ_i, channel_out has a wavelength of λ_j, and the status of the data channel 205 is "0", which means the data channel reservation is in progress. The initial data channel reservation process is now completed.

[0034] If no unreserved outbound data channel 205 is found or a router (core 110 or edge 115) in the path decides not to continue the path setup process, it will send back a negative DCR-acknowledgement (DCR-NAK) message 710 all the way to the electronic ingress edge router E_1. Thus, the attempt by the electronic ingress edge router E_1 to establish a reserved data channel 205 path failed. To insure the error-free transmission and receiving of signaling messages, the signaling processor (both 315 and 515) may be required to send back an acknowledgement (ACK) message to its upstream node when it receives a DCR-Request, DCR-ACK or DCR-NAK. Some time-out mechanism may be used to cope with possible loss of signaling messages.

[0035] Electronic ingress edge router E_1 creates a new queue 1005 after receiving the DCR-ACK 710 from optical core router C_1 as shown in FIGURE 10. This new queue 1005 is used to accommodate the flow bursts to be sent on the reserved data channel λ_i. To reduce or largely eliminate the gaps/voids between bursts sent on the reserved data channel 205, a threshold γ is maintained for the new queue 1005, the value of which could be the traffic volume in bytes or the number of bursts in the new queue 1005. Once the threshold γ is exceeded, the burst flow will be directed to the common queue 1010 until the quantity in the new queue 1005 is dropped below the threshold. A special bit in the burst header packet, called reserved data channel (RC) bit, is used to indicate whether a burst is transmitted on the reserved data channel 205. For bursts sent on the reserved data channel 205, their RC bit is set to 1.

[0036] The actual reservation of the data channels 205 along the optical path is made by the first bursts of the burst flow sent from electronic ingress edge router E_1 on outbound data channel λ_i. For instance, upon receiving the first BHP with RC=1 from data channel λ_i, the scheduler 535 of optical core router C_1 will do the following: (1) reserve the outbound data channel λ_j and configure the optical switching matrix to connect inbound data channel λ_i to outbound data channel λ_j when the first burst is switched; (2) update the status bit in the CIB 550 (see FIGURE 9) from 0 to 1, indicating data channel λ_i and data channel λ_j are now reserved, (3) move data channel λ_j from the unreserved and reservation in progress channel subset to the reserved channel subset in the CIB 550, and (4) change the status of data channel λ_i and data channel λ_j from reservation in progress to reserved in the fiber and channel database 510. At this point, all incoming bursts on data channel λ_i with RC=1 will be switched to outbound data channel λ_j, and no data channel 205 scheduling is need for data channel λ_j. To prevent the potential loss of the first burst

of the flow at an optical core router 110 in the reserved data channel 205 path due to traffic congestion, this burst (with RC=1) may have higher priority in the scheduler 535.

[0037] The same procedure is repeated at optical core routers C_2, C_3, and C_4. So when the first burst with RC=1 reaches optical core router C_4, a reserved data channel path is established (see FIGURE 2), and routers C_1, C_2 and C_3 need not perform any scheduling for the reserved data channels. At optical core router C_4, bursts received on the reserved data channel path will have their RC bits reset to 0 by the scheduler 535 (optical core router C_4 is a RTN). Note that no bandwidth is wasted during the entire data channel reservation process as bursts are still forwarded or switched as before during this period. Note also that BHPs are always forwarded or switched at the switch control unit (SCU) 530 although data channels λ_i and λ_j are cross-connected. A CIB 550 table lookup is required for bursts received from reserved data channels.

[0038] If an electronic ingress edge router 105 decides to terminate the reserved data channel path, either because the average rate of the burst flow is below $R+\Delta$ or for other reasons, it simply sends a burst with an unreserved channel bit RC=0 on outbound data channel λ_i. After receiving one or more bursts with RC=0 on the reserved inbound data channel, an optical core router 110 will terminate the reservation, update the CIB 550 and the fiber and channel database 510 (e.g., removing the entry of data channels λ_i and λ_j in the CIB 550 and moving them to the unreserved channel subset, if the optical core router is C_1), and resume the normal forwarding and/or switching for new arriving bursts. The optical core router 110 will also send a confirmation message back to electronic' edge router E_1. Again, no bandwidth is wasted during the reservation termination process.

[0039] To prevent malfunctions in the electronic ingress edge routers 105 or optical core routers 110, a timer (not shown) is maintained in each router (105, 110 or 115) along the path, which should be reset by a refresh message sent by the electronic ingress edge router 105 before it expires. If the timer expires, the corresponding router will terminate the channel reservation and inform others routers.

[0040] In general, if the average bit rate of the flow is $m{\cdot}R+\Delta(m)$ where m is a nonnegative integer, up to m data channel 205 paths could be reserved. These data channel 205 paths may follow the same route or different routes, but have the same RTN. The number of channels in a data channel 205 path could be more than one. The threshold $\gamma(m)$ now is a function of m. The above data channel reservation method is also valid if an electronic ingress edge router 105 has more than one RTN.

[0041] The data channel reservation method of the present invention is flow-driven, initiated by ingress edge router on demand, protocol independent, and adaptive to the average bit rate of a flow of bursts. The data channel reservation method of the present invention is also suitable for both loose and strict definitions of burst flows. A burst flow is loosely defined as a set of bursts which have the same electronic ingress edge router 105, follow the same path, and are destined to the same reservation termination node (RTN). The strict definition of a burst flow requires that the bursts have the same or similar attributes like quality of service (QOS). The data channel reservation method can also be combined with a layer 2 protocol like MPLS to establish a label switched path (LSP) with bandwidth reservation. Note that the above data channel reservation approach is also suitable for establishing a path with certain reserved bandwidth (of data channels 205) in the optical burst-switched network 100 even if the flow driven factor is not considered.

[0042] In summary, the present invention provides a system and method for reserving data channels in an optical burst-switched network. A data channel (or a multiple of data channels) along an optical path in an optical burst-switched network is reserved by first transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node. Next, the data channel reservation request is processed at all nodes along the path. A data channel reservation acknowledgement is then transmitted from the reservation termination node to the electronic ingress edge router. Finally, the data channel path is reserved once an initial burst(s) which contains a reserve data channel bit reaches the reservation termination node.

[0043] Although the present invention has been described in detail, it should be understood that various changes, substitutions and alterations can be made hereto without departing from the spirit and scope of the invention as described by the appended claims.

Claims

1. A method for reserving a data channel along an optical path in an optical burst-switched network, comprising the steps of:

   transmitting a data channel reservation request from an electronic ingress edge router to a reservation termination node;
   processing said data channel reservation request at said reservation termination node;
   transmitting a data channel reservation acknowledgement from said reservation termination node to said electronic ingress edge router; and
   reserving said data channel once an initial burst comprising a reserve data channel bit reaches said reservation termination node.

2. The method of Claim 1, further comprising the steps of:

   monitoring a burst flow bit rate;
   locating an unreserved data channel between said electronic ingress edge router and said reservation termination node when said flow of bursts exceeds a threshold bit rate;
   creating a new queue in said electronic ingress edge router for accommodating said flow of bursts to be transmitted on said data channel; and
   returning a negative data channel request acknowledgement from a core router or said reservation termination node along said optical path to said ingress edge router if there is no said unreserved data channel available between said core router and said reservation termination node.

3. The method of Claim 1, wherein a plurality of data channels are reserved along said optical path in said optical burst-switched network.

4. The method of Claim 1, wherein said reservation termination node can either be an egress edge router or an optical core router.

5. The method of Claim 4, wherein said data channel reservation request is transmitted from said optical core router to said reservation termination node.

6. The method of Claim 4, wherein a plurality of said optical core routers can be between said electronic ingress edge router and said reservation termination node.

7. The method of Claim 6, wherein said data channel reservation request is processed at each optical core router between said electronic ingress edge router and said reservation termination node.

8. The method of Claim 4, wherein said electronic edge router comprises:

   a plurality of input/output ports;
   a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
   a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
   a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
   a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
   a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network; and
   a first forwarding information base for storing next hop information for arriving bursts.

9. The method of Claim 8, wherein said next hop can either be said electronic egress edge router or said optical core router.

10. The method of Claim 8, further comprising the step of updating said first routing information base and first forwarding information base in said electronic edge router with information on changes in network status received at said electronic edge router.

11. The method of Claim 8, wherein said network information stored in said first fiber and channel database includes inbound and outbound fibers, wavelengths within each said inbound and outbound fibers, inbound and outbound data and control channel groups, channels within each said data and channel control groups, mapping of said data and control channel groups, said channels to said fibers and wavelengths, and the status of each said inbound and said outbound data channel.

12. The method of Claim 11, wherein said first scheduler comprises a first channel information base, said first channel information base operable to store a subset of said information stored in said first fiber and channel data base.

13. The method of claim 1, wherein said optical core router comprises:

   a plurality of input/output ports;
   a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
   a second signaling processor operable to transmit and receive optical burst-switched network

information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

14. The method of Claim 13, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts and their associated burst header packets on data and control channel groups, respectively;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

15. The method of Claim 14, wherein said second scheduler comprises a second channel information base, said second channel information base operable to store a subset of said information stored in said second fiber and channel data base.

16. The method of Claim 2, wherein said unreserved data channel can be located either by default route or by explicit route.

17. The method of Claim 1, wherein said data channel can be in one of three possible states including an unreserved state, a reservation in progress state, or a reserved state.

18. A method for terminating a reserved data channel in an optical burst-switched network, comprising the steps of:

transmitting a burst with a burst header packet comprising an unreserved data channel bit from an electronic ingress edge router to a reservation termination node along a reserved data channel path;
processing said unreserved data channel bit at said reservation termination node;
transmitting a confirmation message from said reservation termination node to said electronic ingress edge router confirming that the reservation of said reserved data channel is terminated.

19. The method of Claim 18, wherein said reservation termination node can either be an egress edge router or an optical core router.

20. The method of Claim 18, wherein said burst with a burst header packet comprising an unreserved data channel bit is transmitted from said optical core router to said reservation termination node.

21. The method of Claim 18, wherein a plurality of said optical core routers are between said electronic ingress edge router and said reservation termination node.

22. The method of Claim 21, wherein said data channel reservation request is processed at each optical core router between said electronic ingress edge router and said reservation termination node.

23. The method of Claim 19, wherein said electronic ingress edge router and said electronic egress edge router both comprise:

a plurality of input/output ports;
a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network;
a first forwarding information base for storing

next hop information for arriving bursts.

24. The method of Claim 23, wherein said first scheduler comprises a first channel information base.

25. The method of claim 19, wherein said optical core router comprises:

a plurality of input/output ports;
a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

26. The method of Claim 25, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts on data control groups and burst header packets on control channel groups;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

27. The method of Claim 26, wherein said second scheduler comprises a second channel information base.

28. A system for reserving a data channel along an optical path in an optical burst-switched network, comprising:

an electronic ingress edge router operable to transmit a data channel reservation request; and
a reservation termination node operable to receive and process said data channel reservation request, transmit a data channel reservation acknowledgement back to said electronic ingress edge router, and receive an initial burst comprising a reserve data channel bit completing the reservation processes.

29. The system of Claim 28, where a plurality of data channels are reserved along said optical path in said optical burst-switched network.

30. The system of Claim 28, wherein said reservation termination node can either be an egress edge router or an optical core router.

31. The system of Claim 30, wherein said data channel reservation request is transmitted from said optical core router to said reservation termination node.

32. The system of Claim 30, wherein a plurality of said optical core routers can be between said electronic ingress edge router and said reservation termination node.

33. The system of Claim 30, wherein said electronic edge router comprises:

a plurality of input/output ports;
a first routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a first fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a first data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a burst flow monitoring module operable to monitor the burst flow between said electronic ingress edge router and said reservation termination node and inform said signaling processor when the burst flow rate exceeds or drops below a given threshold;
a first scheduler operable to schedule the transmission of bursts on data channel groups and their associated burst header packets on control channel groups;
a first routing information base for storing all necessary optical burst-switched network routing information for said optical burst-switched network; and
a first forwarding information base for storing next hop information for arriving bursts.

34. The system of Claim 33, wherein said next hop can either be said electronic egress edge router or said optical core router.

35. The system of Claim 33, wherein said first routing information base and first forwarding information base in said electronic edge router are updated with information on changes in network status received at said electronic edge router.

36. The system of Claim 33, wherein said network information stored in said first fiber and channel database includes inbound and outbound fibers, wavelengths within each said inbound and outbound fibers, inbound and outbound data and control channel groups. channels within each said data and channel control groups. mapping of said data and channel control groups. said channels to said fibers and wavelengths. and status of each said inbound and said outbound data channel.

37. The system of Claim 36. wherein said first scheduler comprises a first channel information base, said first channel information base operable to store a subset of said information stored in said first fiber and channel data base.

38. The system of claim 29, wherein said optical core router comprises:

a plurality of input/output ports;
a second routing processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second signaling processor operable to transmit and receive optical burst-switched network information from neighboring communication devices through said input/output ports;
a second fiber and channel database for receiving and storing optical burst-switched network information from said routing processor and said signaling processor;
a second data channel path management module operable to monitor all data channel paths which are already reserved or in the process of being reserved;
a second routing information base for storing all necessary routing information for said optical burst-switched network; and
a switch control unit operable to configure an optical switching matrix to switch said bursts through said optical burst switched network.

39. The system of Claim 38, wherein said switch control unit comprises:

a second scheduler operable to schedule the transmission of bursts and their associated burst header packets on data and control channel groups, respectively;
a second forwarding information base for storing next hop information for arriving bursts; and
a first label information base for storing label-swapping information.

40. The system of Claim 39, wherein said second scheduler comprises a second channel information base, said second channel information base operable to store a subset of said information stored in said second fiber and channel data base.

41. The system of Claim 28, wherein said data channel can be in one of three possible states, including an unreserved state, a reservation in progress state, or a reserved state.

42. A system for terminating a reserved data channel in an optical burst-switched network, comprising:

an electronic ingress edge router operable to transmit a burst comprising an unreserved data channel bit from said electronic ingress edge router to a reservation termination node; and
a reservation termination node operable to receive said burst comprising said unreserved data channel bit, process said unreserved data channel bit, and transmit a confirmation message to said electronic ingress edge router confirming that said reservation of said reserved data channel is terminated.

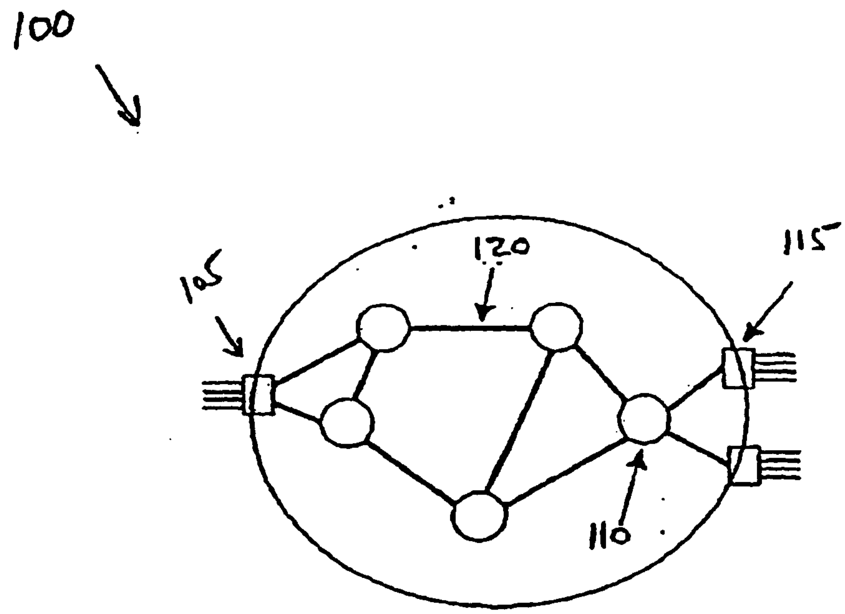

Figure 1: An optical burst-switched network.

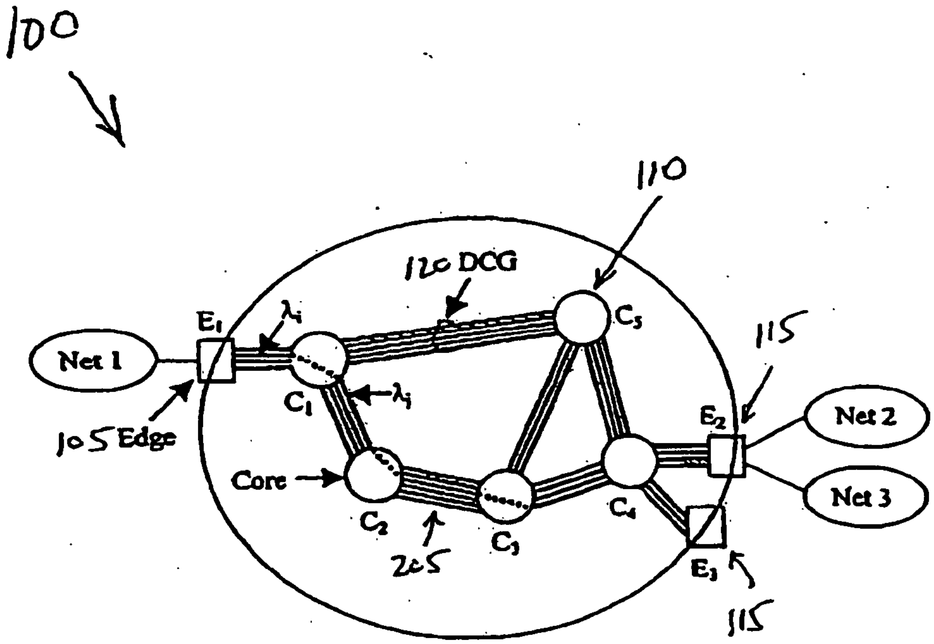

Figure 2: An optical burst-switched network.

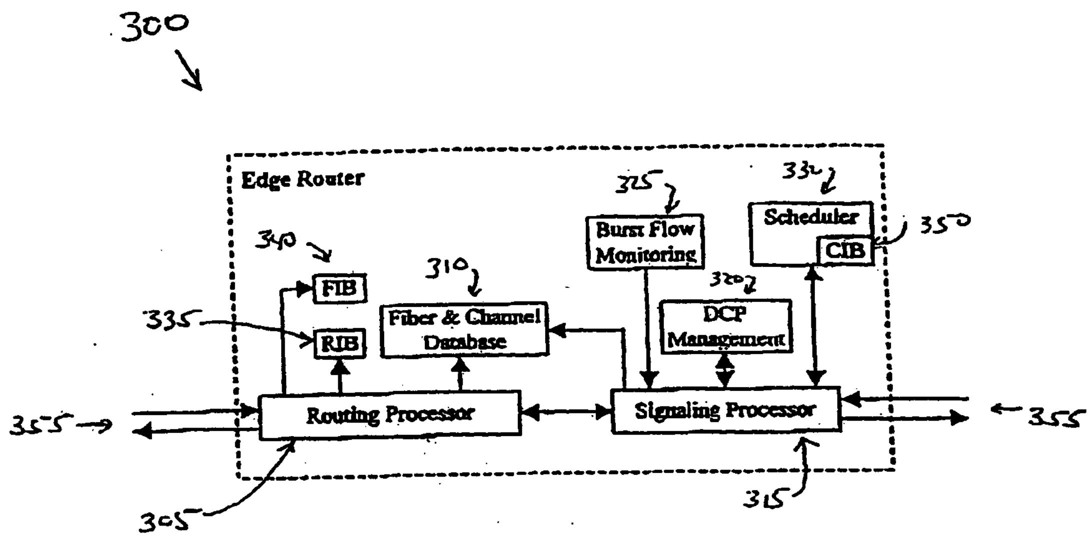

Figure 3: Relevant function blocks at an edge router.

400

IP address	DCG_out	Label_out
A_1	G_a	L_x
A_2	G_b	L_y

Figure 4: Sample forwarding information base (FIB) at an edge router.

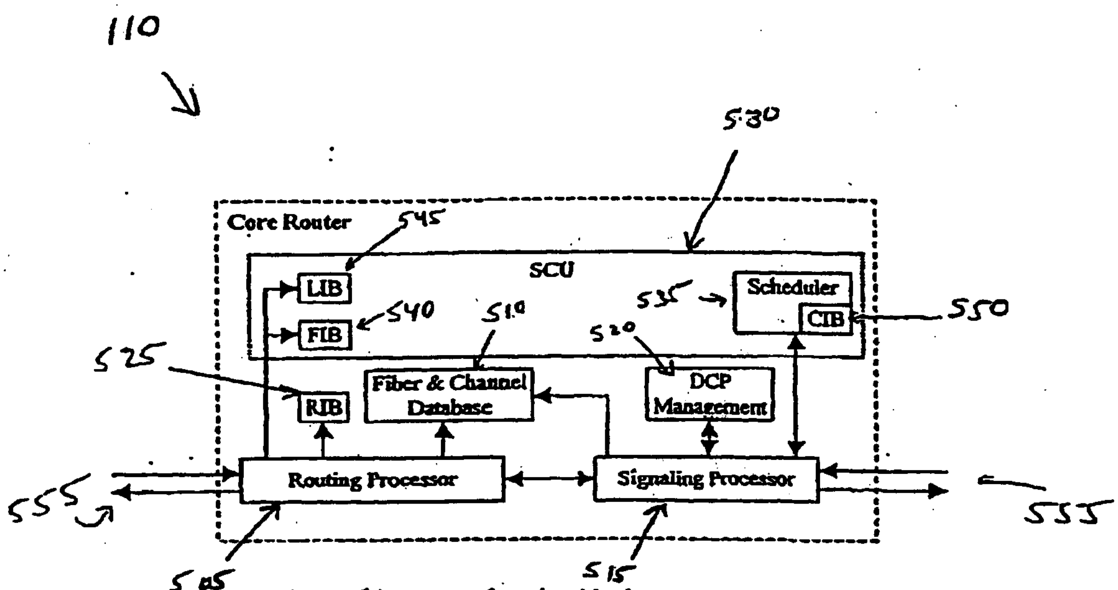

Figure 5. Relevant function blocks at a core router.

600

DCG_in	Label_in	DCG_out	Label_out
G_a	L_b	G_c	L_d
G_e	L_f	G_g	L_h

Figure 6 : Sample label information base (LIB) at a core router.

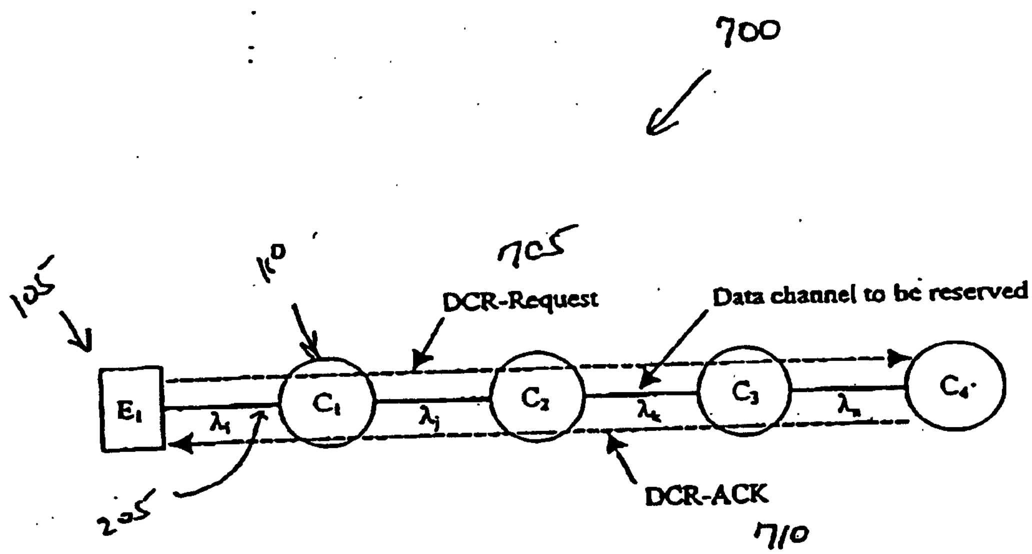

Figure 7 Data channel path setup.

800

DCG_in	Channel_in	Channel_out	Status
G_p	λ_u	λ_v	1
G_q	λ_n	-	0

Figure 8 Sample channel information base (CIB) at core router C_4.

900

DCG_in	Channel_in	Channel_out	Status
G_r	λ_x	λ_y	1
G_s	λ_r	λ_y	0

Figure 9 Sample channel information base (CIB) at core router C_1.

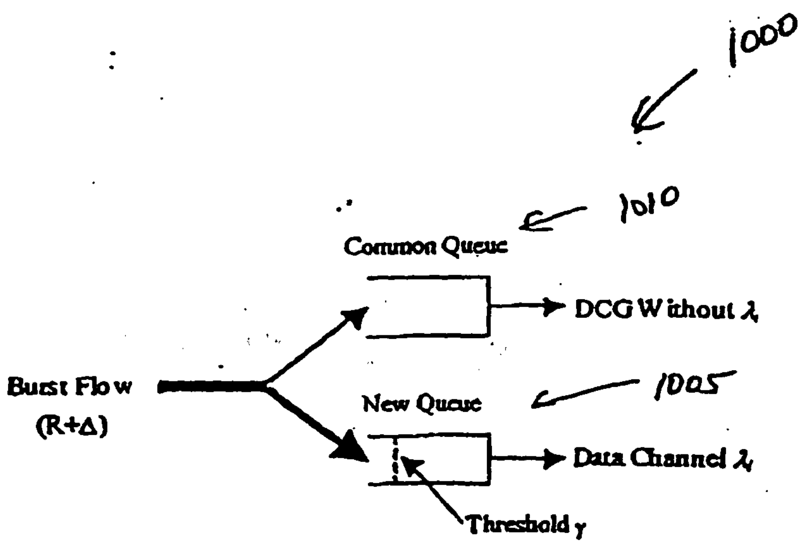

Figure 10. A new queue with some threshold for the reserved data channel.